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Low-Noise Cryogenic Transmission Line

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New low-noise cryogenic input transmission lines have been developed for the DSN at 1.668 GHz and 2.25 GHz for cryogenically cooled Field Effect Transistor (FET) and High Electron Mobility Transistor (HEMT) amplifiers. These amplifiers exhibit very low noise temperatures of 5 K to 15 K, making the requirements for a low-noise input transmission line critical. Noise contribution to the total amplifier system from the low-noise line is less than 0.5 K for both the 1.668-GHz and 2.25-GHz FET systems. The 1.668-GHz input line was installed in six FET systems which were implemented in the DSN for the Venus Balloon Experiment. The 2.25-GHz input line has been implemented in three FET systems for the DSN 34-m HEF antennas, and the design is currently being considered for use at higher frequencies.

I. Introduction

The purpose of the cryogenic input transmission line is to direct a desired RF signal from the room-temperature environment to the input of a cryogenically cooled amplifier while adding as little noise as possible. This article describes the design and performance of a cryogenically cooled coaxial probe transmission line that adds less than 0.1 K to the noise temperature of a maser amplifier and less than 0.5 K to the noise temperature of a cryogenic transistor amplifier. This input line was first designed and implemented in 1973 [1] for 2.3-GHz traveling-wave maser (TWM)/closed-cycle refrigerator (CCR) systems, which operate at a physical temperature of 4.5 K. More recently, the line was redesigned for 1.668-GHz and 2.25-GHz FET/CCR and HEMT/CCR systems, which operate at a 12-K nominal physical temperature. The FET amplifier, as well as the similar high electron mobility transistor (HEMT) amplifier, has a much wider bandwidth than masers, and the coaxial probe unit was successfully broadbanded for 1.668- and 2.25-GHz use as a result of this design effort.

II. Design

Figure 1 shows a cutaway view of the low-noise cryogenic transmission line assembly. Figure 2 is a photograph of the input transmission line installed on a TWM/CCR assembly. Figure 3 is a photograph of the components. The RF input signal comes into the WR 430 waveguide flange and is coupled to a coaxial probe. A quartz dome window in the waveguide establishes a vacuum environment for the entire probe/center conductor, which is cantilever-supported from the cold (4.5-K or 12-K) end. The entire length of the probe/coaxial center conductor can be cooled to the CCR first-stage temperature. Since a major portion of the insertion loss and noise of a coaxial line is contributed by the center conductor's resistivity and physical temperature, this approach provides very low noise contribution.

A waveguide shorting plate is placed at one end of the waveguide approximately 1/4 wavelength behind the probe. The outer coaxial conductor is thin-wall SS tubing plated in the inside surface with a few skin depths of copper (120 microinches nominal). This copper thickness is adequate for RF surface conductivity but does not significantly degrade the thermal insulation provided by the SS tubing, which is tied to room temperature at one end, to the 70-K heat station, and to the 4.5-K (or 12-K in the case of HEMT coolers) final heat station in the CCR.

The impedance of the coaxial line was chosen to be 77 ohms for minimum loss (as described in [2]) and is transformed to 50-ohm output impedance at the SMA connector with a step transformer.

Figure 4 shows a Smith chart with sample data of the tuning process (as described in [3]) that was followed to optimize both the distance from the probe to the waveguide shorting plate and the length of the probe within the WR 430 waveguide cavity. This was done at a single frequency representing the desired band center. The four curves were obtained for the four labeled probe-to-shorting plate dimensions, and each data point on each curve represents a different probe length in 0.51-cm increments. In this manner, the optimum dimensions can be obtained by interpolation of the data for point A. In the case of the 2.25-GHz assembly, the optimum dimensions were found to be 3.048 cm for the probe length and 3.302 cm for the probe-to-back short. Increased bandwidth was obtained by the addition of shunt capacitance near the SMA connector.

III. Performance

The measured return loss of the assembled transmission line (shown in Fig. 5) is greater than 20 dB between 2.00 GHz and 2.60 GHz. The heat load on a three-stage, 4.5-K CCR is less than 100 milliwatts. The contribution to the input noise temperature of a 2.3-GHz maser amplifier (in a 4.5-K CCR) is estimated to be less than 0.1 K. The contribution to the noise temperature of the 2.3-GHz HEMT and FET amplifiers (in a 12-K CCR) is less than 0.5 K.

IV. Conclusions

The 1.668-GHz low-noise cryogenic transmission line input assembly was implemented for the first time in six FET/CCR systems in support of the Venus Balloon Experiment. The 2.25-GHz input is also being used in the Deep Space Network in a HEMT/CCR at DSS-13 and in three FET/CCRs at DSS-15, DSS-45, and DSS-65. These transmission lines provide sufficient bandwidth to be useful with the bandwidths achieved by state-of-the-art cryogenic FET and HEMT amplifiers. This design is now being considered for use at higher frequencies as a more compact alternative to waveguide input transmission lines.

References

[1] R. Clauss and E. Wiebe, *JPL Technical Report 32-1526*, vol. XIX, February 15, 1974.

[2] S. F. Adam, *Microwave Theory and Applications*, New York: Prentice-Hall, pp. 37–41, 1969.

[3] G. L. Ragan, "Microwave Transmission Circuits," MIT Radiation Laboratory Series, New York: McGraw-Hill, pp. 318–322, 1948.

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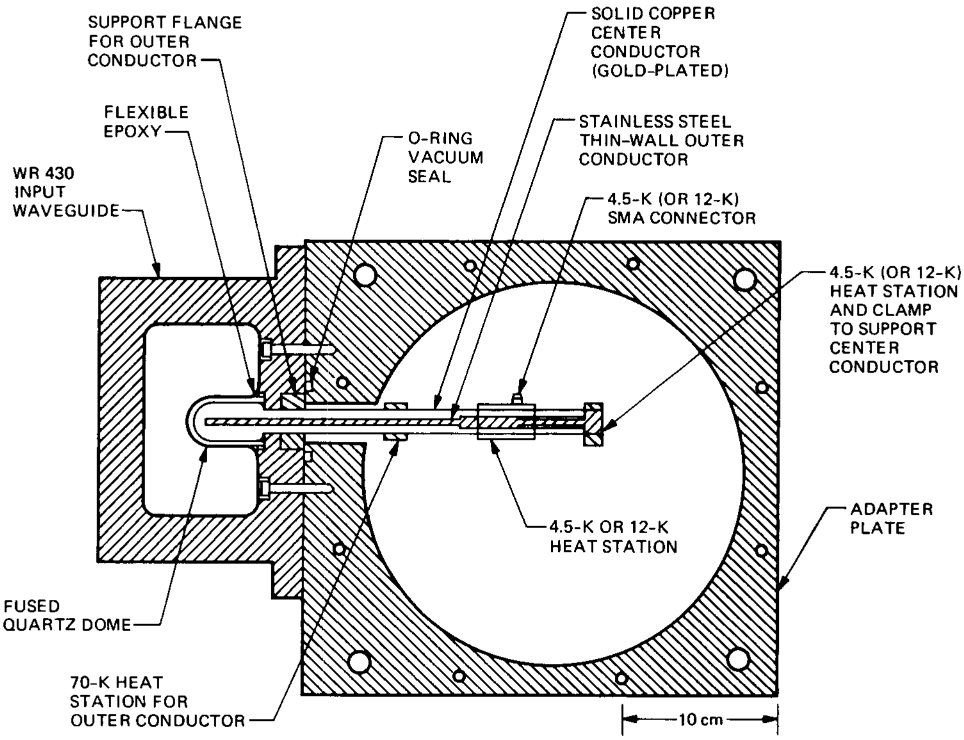

Fig. 1. Cutaway view of cryogenic input transmission line assembly maser configuration (FET and HEMT applications are similar)

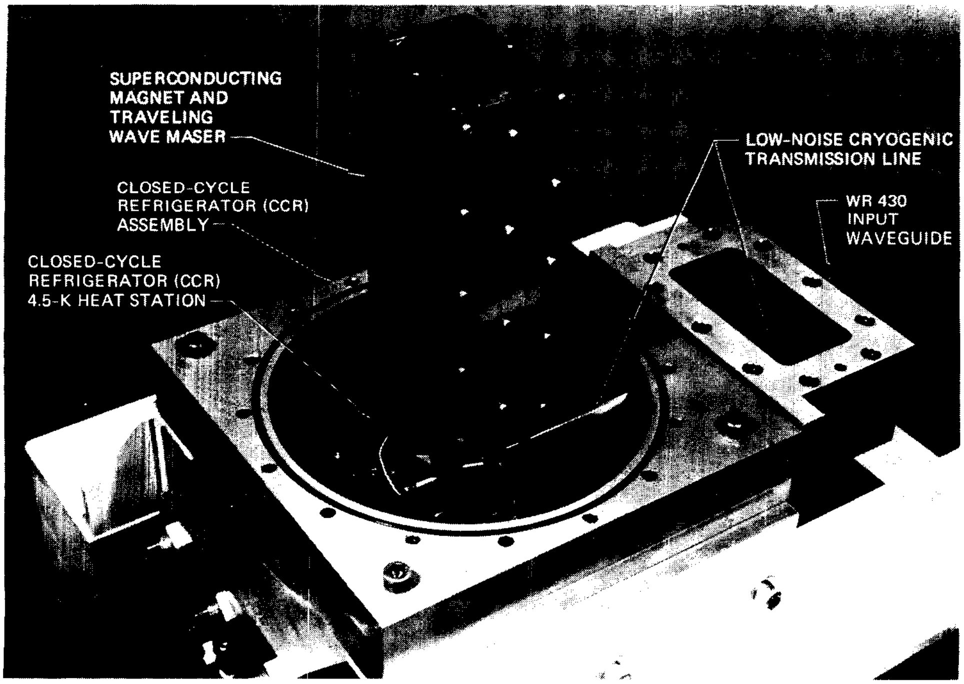

Fig. 2. A 2.3-GHz traveling-wave maser (vacuum housing and radiation shields are partially removed)

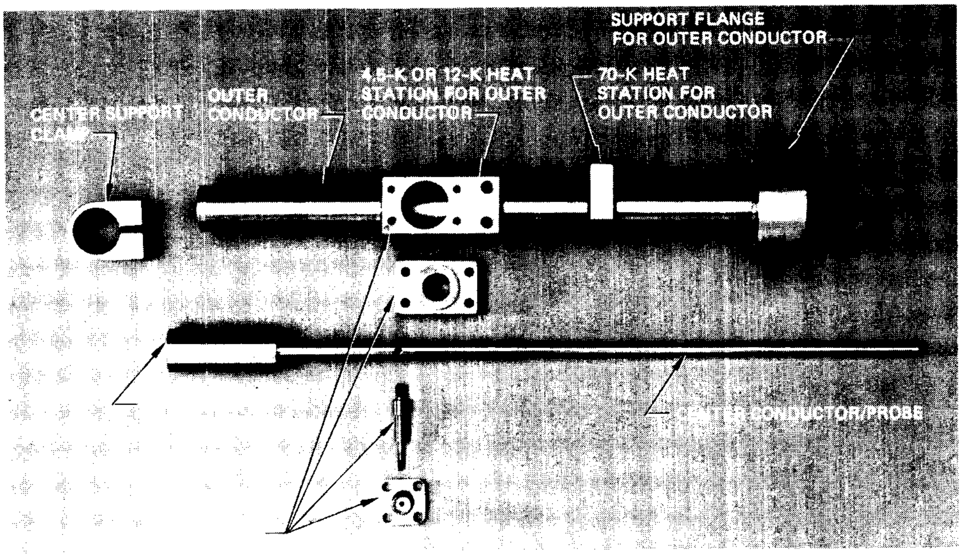

Fig. 3. Components of cryogenic input transmission line

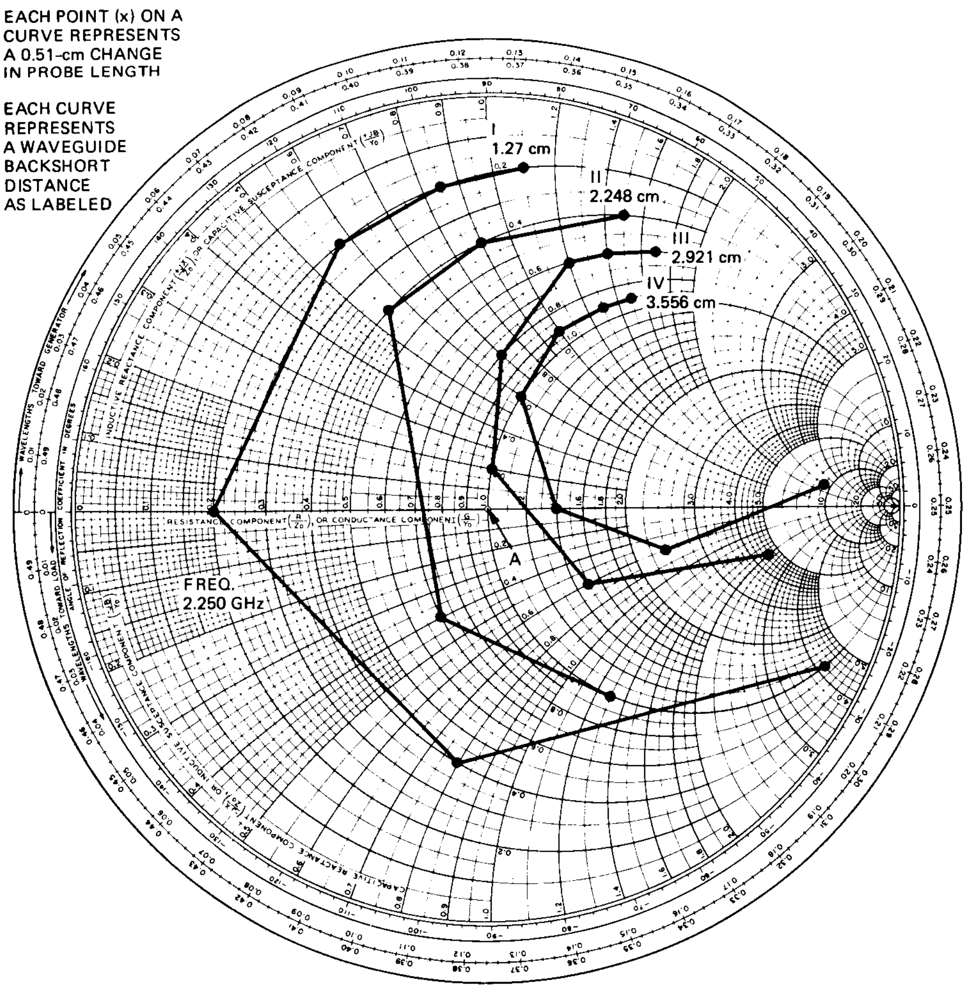

Fig. 4. Smith-chart plot of 2.25-GHz transmission line assembly S_{11}

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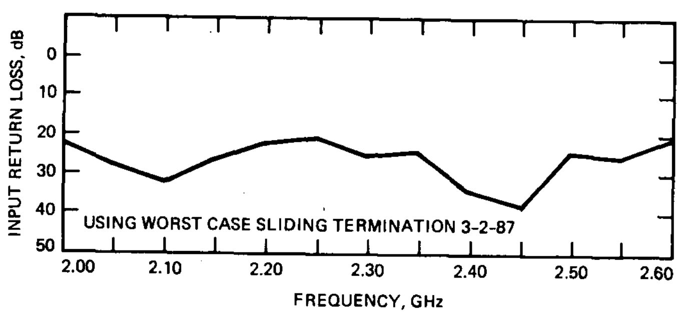

Fig. 5. Return loss versus frequency at 2.25 GHz